TAHOE: STATE OF THE LAKE REPORT 2023

BIOLOGY

UC DAVIS
Tahoe Environmental Research Center

Algae growth (primary productivity)

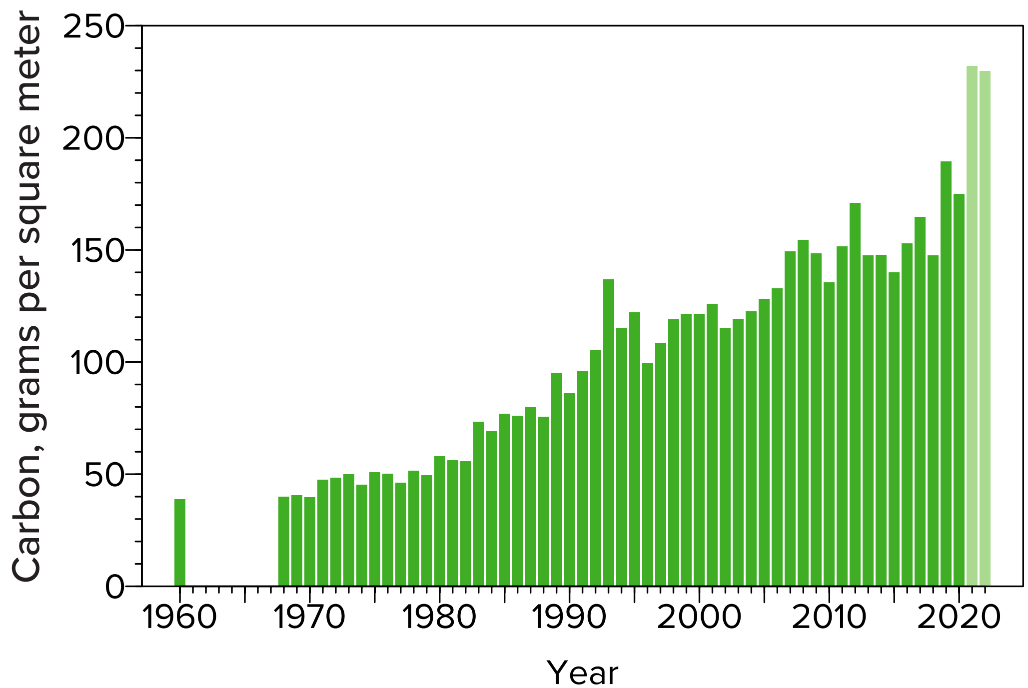
Yearly since 1959

Primary productivity is a measure of the rate at which algae produce biomass (carbon) through photosynthesis. It was first measured at Lake Tahoe in 1959 and was measured continuously since 1968. Supported by nutrient loading into the lake, changes in the underwater light environment, and the succession of algal species, the long-term trend shows that primary productivity has increased substantially over time. After a comprehensive review of changes in the methodologies used for this complex measurement over time the dataset has been revised. While the long-term increasing trend has not changed, the magnitude of the annual averages was reduced by an average of 32%.

The corrected data show that over the last 55 years, there was a 480% increase in primary productivity. In 2022, the annual average primary productivity attained a very high value of 230 mg of carbon per m^2, similar to the value for 2021. Both years displayed extremely high standard deviations (250 and 322 mg of carbon per m^2, respectively), indicative of highly fluctuating month-to-month values.

While significant uncertainties remain, the increase in primary productivity in 2022 is believed to be associated with a combination of environmental factors that favored the seasonal dominance of larger phytoplankton such as the diatom *Synedra*, the major biomass contributor, and the filamentous cyanobacteria, *Leptolyngbya sp.* which was the most abundant species in both 2021 and 2022.

Data source: TERC lake monitoring.



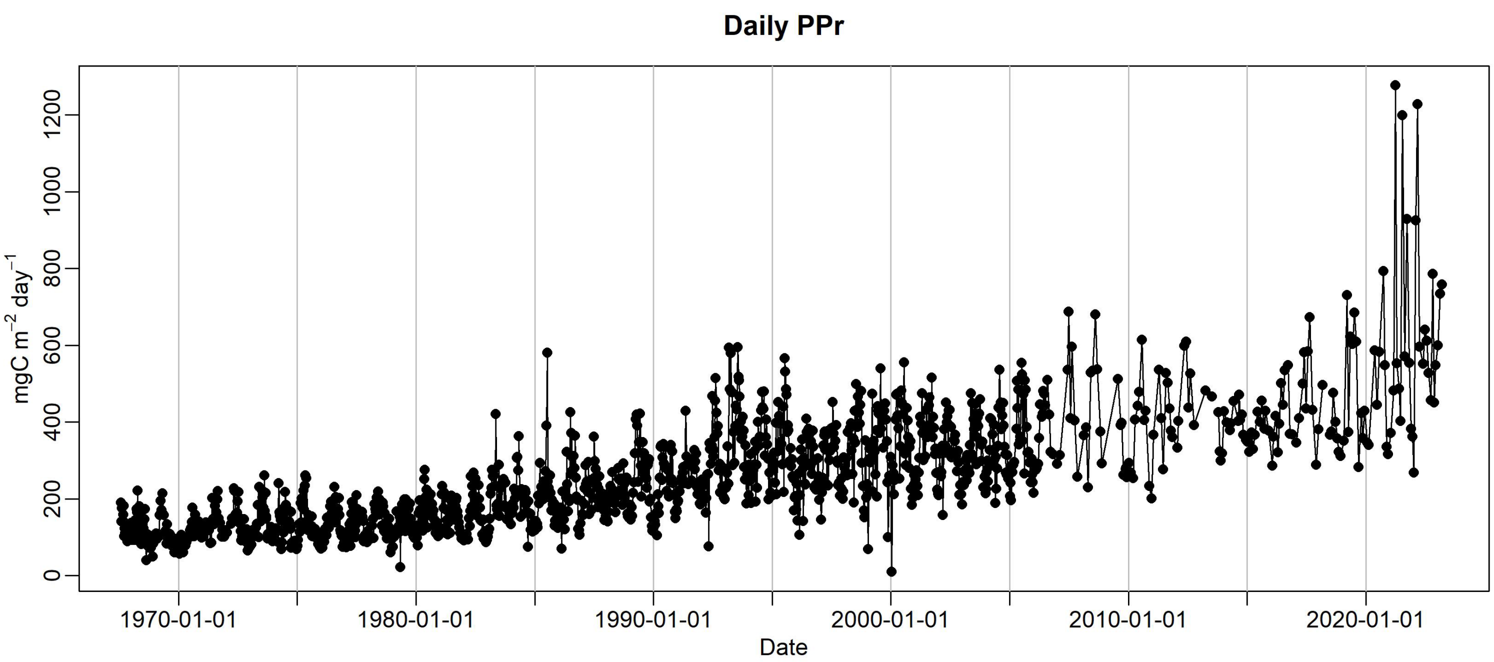
Algae growth (primary productivity)

Monthly since 1968

The primary productivity (PPr) is determined through measuring the depth-averaged uptake of isotopic Carbon-14 in a set of transparent and opaque bottles deployed for four hours at 12 depths (2, 5, 10, 15, 20, 30, 40, 50, 60, 75, 90, and 105 m). The bottles span the entire euphotic zone (the light penetrating zone). The vertical distribution of the phytoplankton that are responsible for the primary production is not uniform across the euphotic zone, but varies depending on light availability, nutrient concentrations, and the distribution of grazers (zooplankton).

In 2021 and 2022 the individual primary productivity readings showed an extremely high level of variability. Most of the peaks are represented as a single point, rather than a number of measurements trending toward and away from a peak. This suggests that the frequency of measurement (once a month) may not be fully resolving the time history of algal blooms.

Data source: TERC lake monitoring.



Biovolume

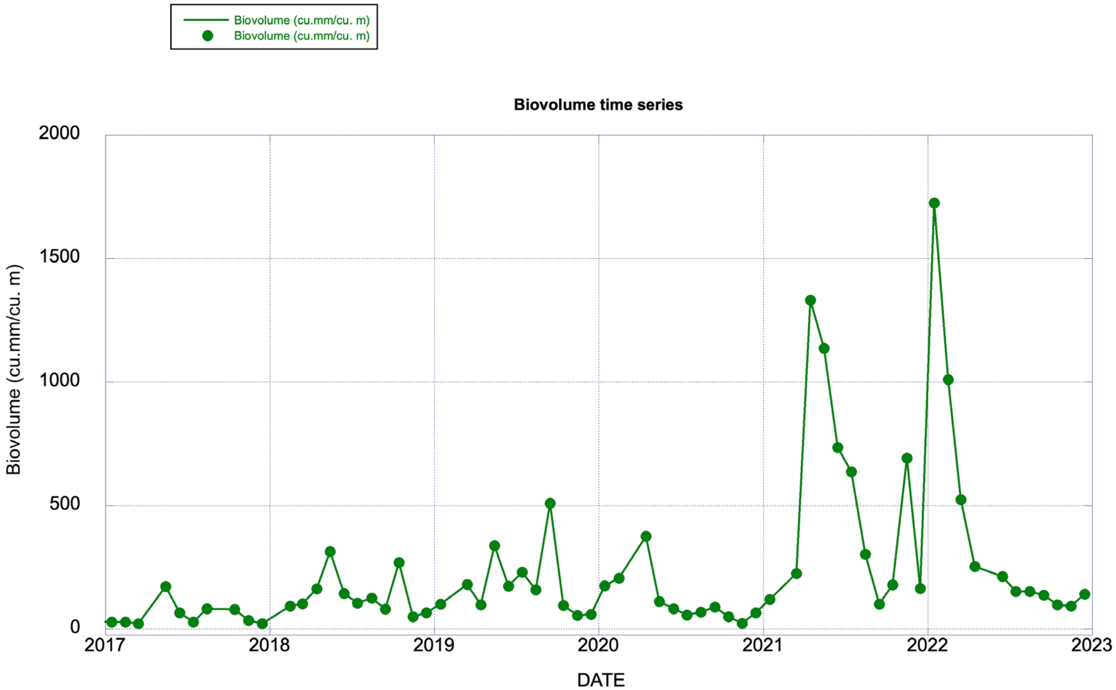
Monthly since 2017

The biovolume (or cell volume) of phytoplankton is an estimate of the concentration of algal biomass. It is a widely reported measurement of phytoplankton abundance in a water sample, based on a time-intensive measurement of water samples. The biovolume is estimated for each individual taxa from formulae for solid geometric shapes that most closely match the cell shape based on algal cell dimension measurements taken from a representative number of specimens. The process for estimation of the biovolume is currently being reviewed. At Lake Tahoe, samples for biomass estimates are taken from 5, 20, 40, 60, 75 and 90 m depths, and an integrated estimate is produced.

The biovolumes in 2021 and 2022 show several extremely high peaks that were not present in the years since 2017. These peaks are not coincident with the peaks in primary production as they represent a fundamentally different measurement. The primary productivity is a rate, while the biovolume is a concentration. Peaks in biovolume occur when the primary productivity is at a minimum.

It is worth noting that the presence of larger algae generally coincides with higher biovolumes, while smaller algae, though far more numerous in abundance, typically coincide with smaller biovolumes. It would require one million tiny alga cells (2 microns in size) to equal the same biovolume of a single large (200 microns) algal cell.

Data source: TERC lake monitoring.

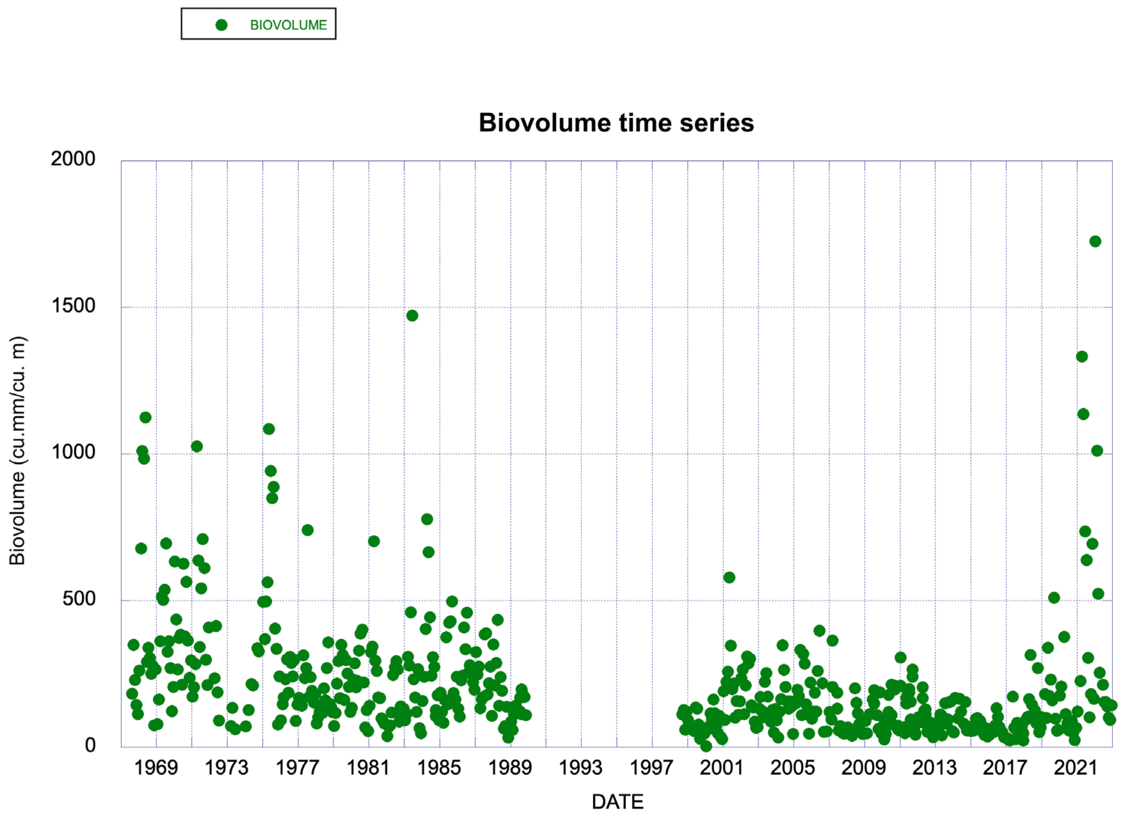


Biovolume

Monthly since 1968

When viewed over the full record, the peaks of 2021 and 2022 do not appear to be anomalous, but rather appear to be a returning to conditions that conditions that occurred in the 1980s and earlier. This observation is consistent with a dominance by larger alga in the 1980s and earlier and the occurrence for parts of the year dominated by larger alga (*Synedra*) in 2021 and 2022. This is a topic that is currently being studied by TERC researchers.

Data source: TERC lake monitoring.

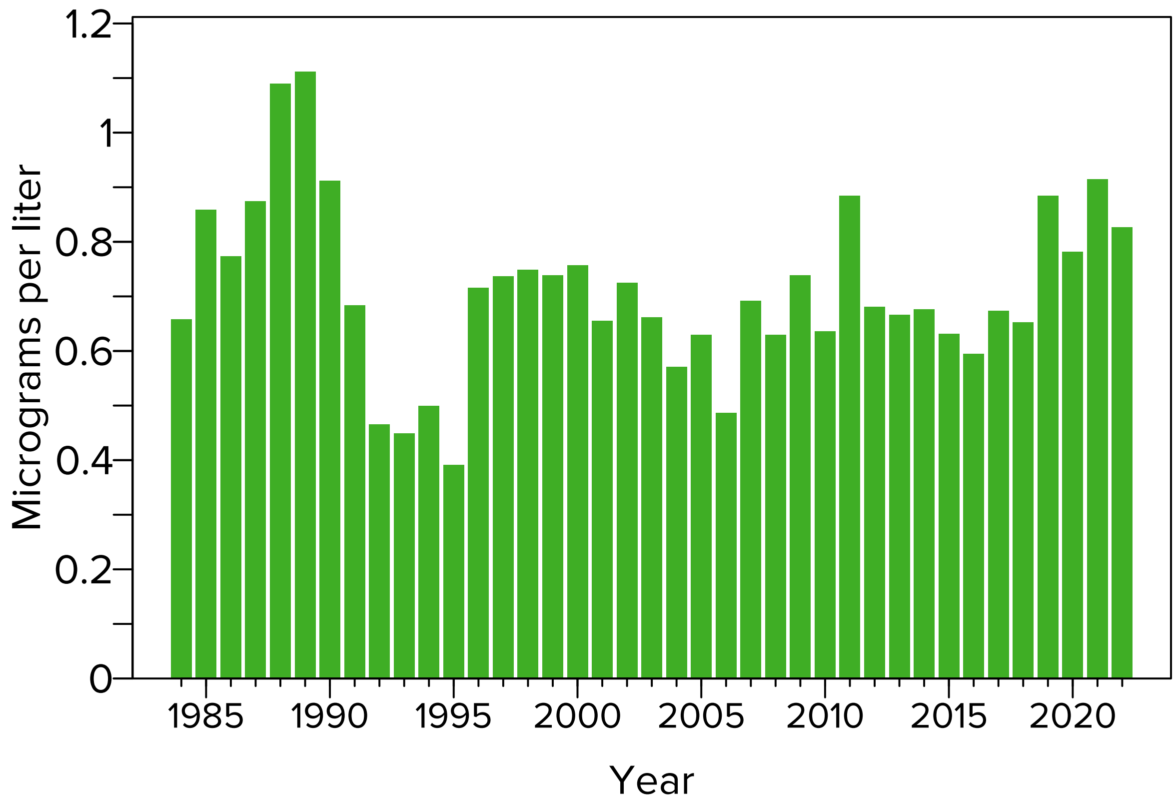


Phytoplankton chlorophyll annually

Yearly since 1984

Phytoplankton (algae) are the base of the Lake Tahoe food web and essential for lake health and the well-being of the entire ecosystem. One measure of the amount, or biomass, of free-floating algae in the water is determined by extracting and measuring the concentration of chlorophyll-*a*. Chlorophyll-*a* is a photosynthetic pigment that allows plants to convert energy from the sun. Though the value varies annually and at different depth throughout the lake, the average concentration has shown remarkable consistency over the last 25 years, and 2022 maintained this pattern. The average annual concentration for 2022 was 0.83 micrograms per liter, a slight decrease from the previous year. For the period of 1984–2022 the average annual chlorophyll-*a* concentration in Lake Tahoe was 0.71 micrograms per liter.

Data source: TERC lake monitoring.

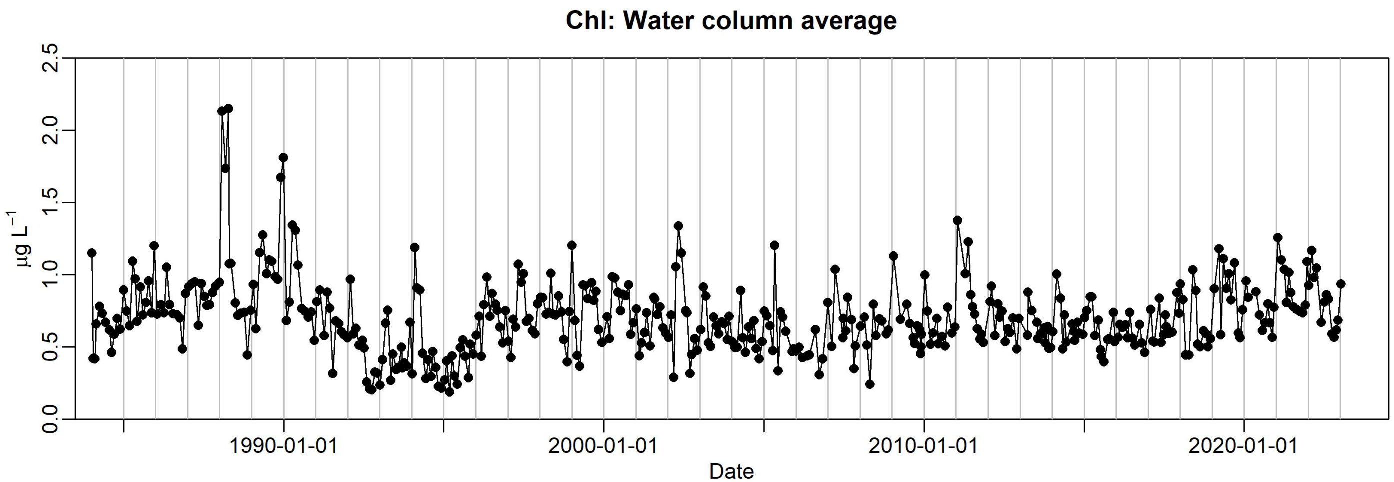


Phytoplankton chlorophyll

Monthly since 1984

The monthly chlorophyll-*a* values have generally reflected the annual trends, showing little systemic long-term trend. The monthly chlorophyll-*a* values have generally reflected the annual variation without presenting any long-term trend. However, the monthly data does show how chlorophyll-*a* concentrations change by a factor of two within each year. The biovolume in Figure 10.4, by contrast, shows a far larger dynamic range over each year.

The data were based on laboratory chlorophyll-*a* extractions from water samples collected at 13 depths of 0, 2, 5, 10, 15, 20, 30, 40, 50, 60, 75, 90, and 105 meters.



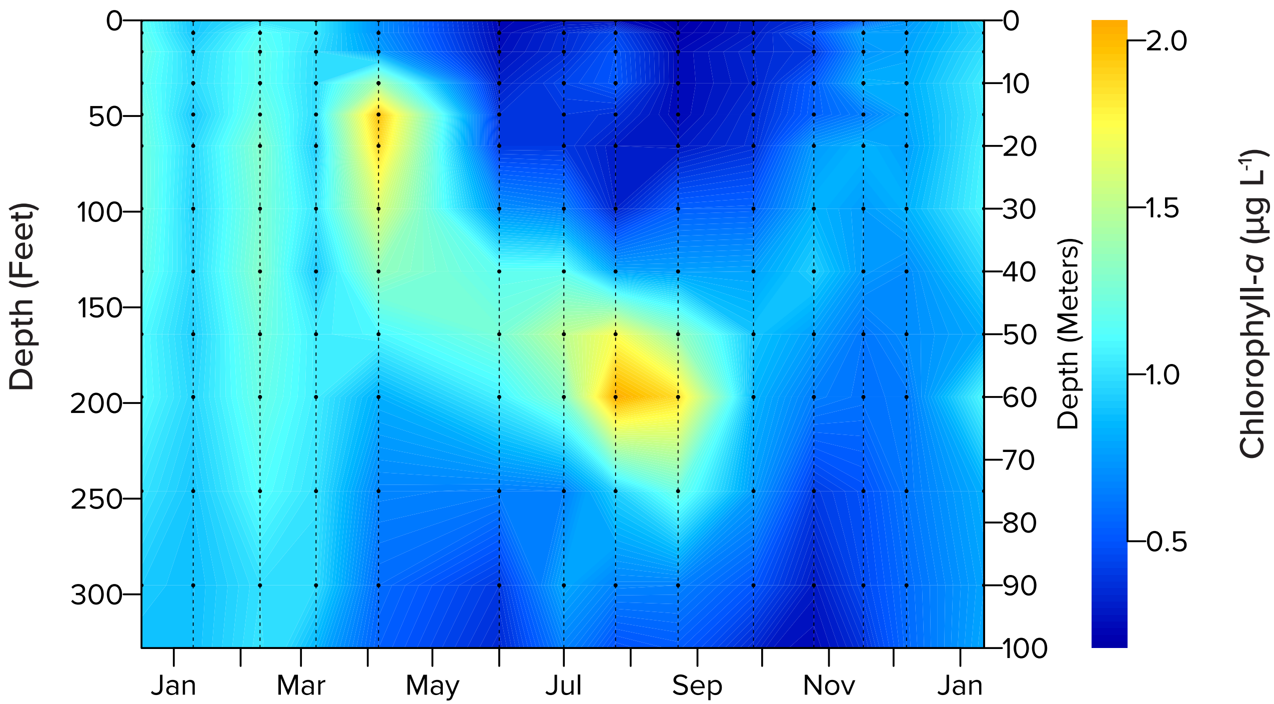
Chlorophyll-*a* spatial distribution

In 2022

The distribution of algae (measured as chlorophyll-*a* concentration) is the result of a combination of light availability, nutrient availability, grazing, mixing processes, and water temperature. This figure shows color contours of chlorophyll-*a* concentration to a depth of 350 feet. Below this depth, chlorophyll-*a* concentrations are near zero due to the absence of light. Lake Tahoe generally has a "deep chlorophyll maximum" (DCM) in the summer that occupies the range of 150–300 feet in the water column. In that range, the light and nutrient conditions are most favorable for algal growth.

In 2022, this pattern changed significantly. At the beginning of the year, chlorophyll was relatively high throughout the water column, an unusual occurrence. In September, the deep chlorophyll layer virtually disappeared and chlorophyll concentrations throughout the upper 300 feet of Lake Tahoe fell to extremely low levels. Based on all the data available for light, nutrients, mixing, and water temperature, none of these factors can account for this singular change in 2022.

The factor that is consistent with the large change in chlorophyll is the change in the nature of zooplankton community that took place in 2022 (see Fig. 10.12). Early in 2022, there was a large decrease in the copepod community. The consequent reduction in grazing pressure on phytoplankton could explain the high chlorophyll in January–March. Likewise, in the latter part of 2022, rotifers occurred in high concentration and eventually cladocerans and copepods returned. This could account for the disappearance of the DCM in September.



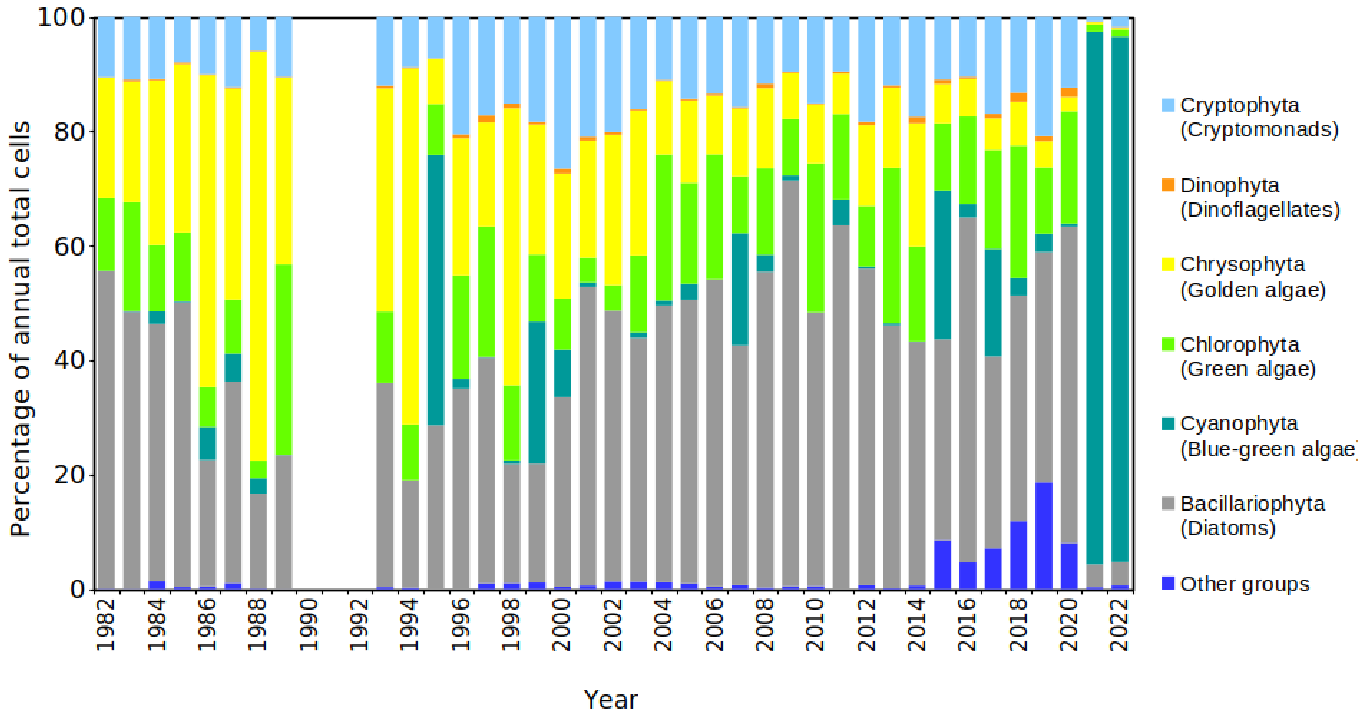
Distribution of algal groups

Yearly since 1982

There are six major taxonomic groups represented in the phytoplankton from Lake Tahoe. The total number of algal cells from different groups varies annually. Diatoms have generally been the most common type of algae. In 2022, a major shift in the phytoplankton composition continued for a second year with continued high abundance (based on cell counts) of the cyanobacteria *Leptolyngbya sp.* and with sporadic contribution of *Pseudanabaena sp.* Both are a multicellular filamentous cyanobacterial genus with similar morphologies. Note that picoplanktonic cyanobacteria are not included. These are the only two years on record in which a single taxon belonging to the cyanobacteria group dominated the phytoplankton assemblage. *Leptolyngbya* is a simple filamentous genus that in Lake Tahoe includes an extremely narrow species, generally with cells a mere 1–2 microns wide. This small size has large impacts on clarity. The cells are enclosed in a sheath and form filaments with variable length (from 50µm to 400µm, frequently ~100µm).

The 2021 and 2022 occurrences (see Figs. 6.10) are actually part of a single, contiguous event. In 2021, the *Leptolyngbya sp.* was dominant from October through December, and in 2022 it was dominant from January through March. The initial cause of the *Leptolyngbya* bloom is believed to be high atmospheric nitrate inputs associated with wildfire smoke.

Data source: TERC lake monitoring.

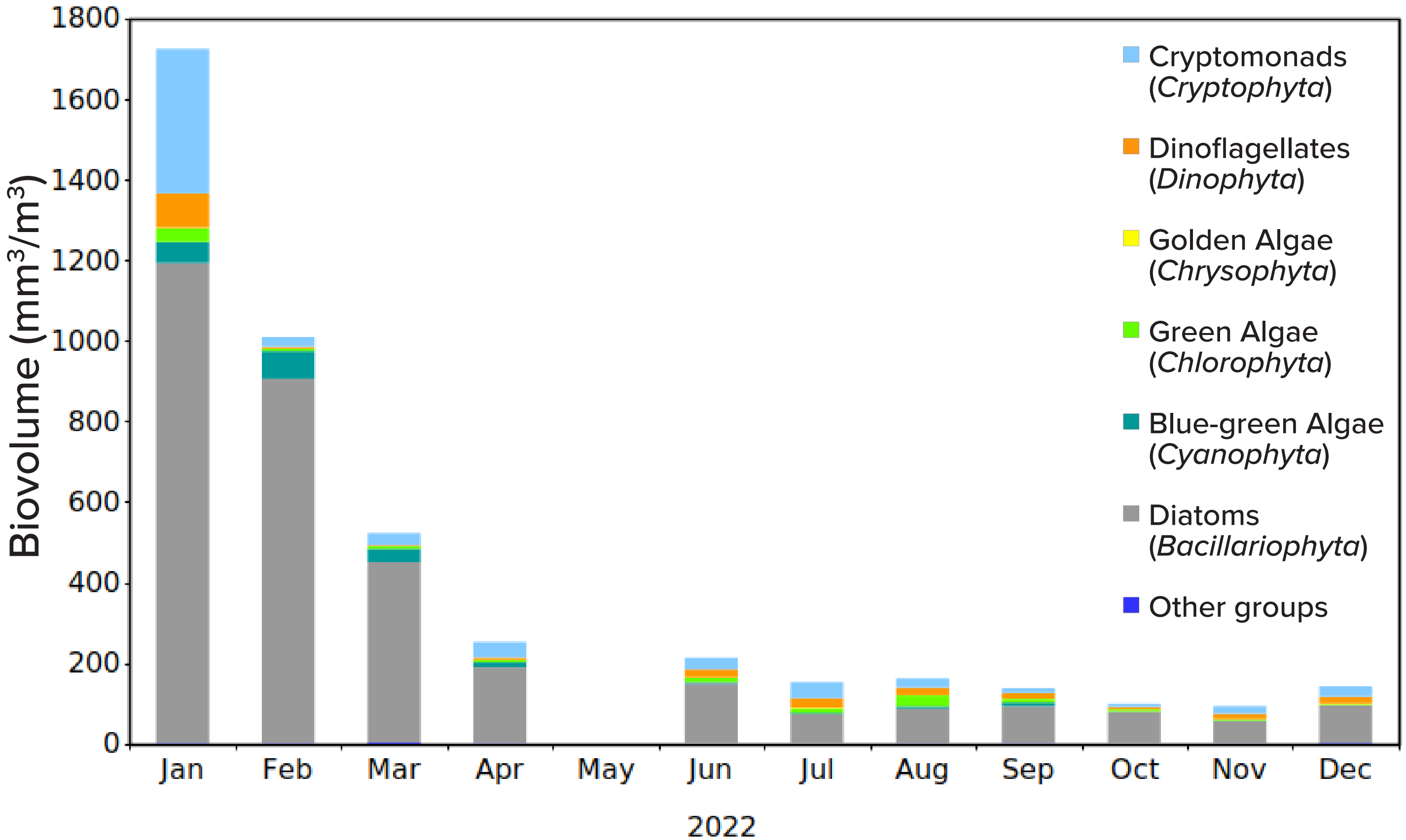


Algal groups as a fraction of total biovolume

Monthly in 2022

The total biovolume of different algal genera vary month to month as well as year to year. In 2022, despite the fact that cyanobacteria dominated algal abundance on the basis of the number of individual cells, diatoms again dominated the biovolume (proportional to the mass) of the phytoplankton community in every month. The peak in the monthly average biovolume occurred in January 2022 and was much higher than normal. This "winter bloom" is highly atypical. The bloom continued through March. As described previously, a possible explanation for the biovolume distributions was a marked decrease in the zooplankton grazing. Though they had little impact on the biovolume, the high abundance of small algae also produced very low clarity values at the same time (See Fig. 11.4)

Data source: TERC lake monitoring.

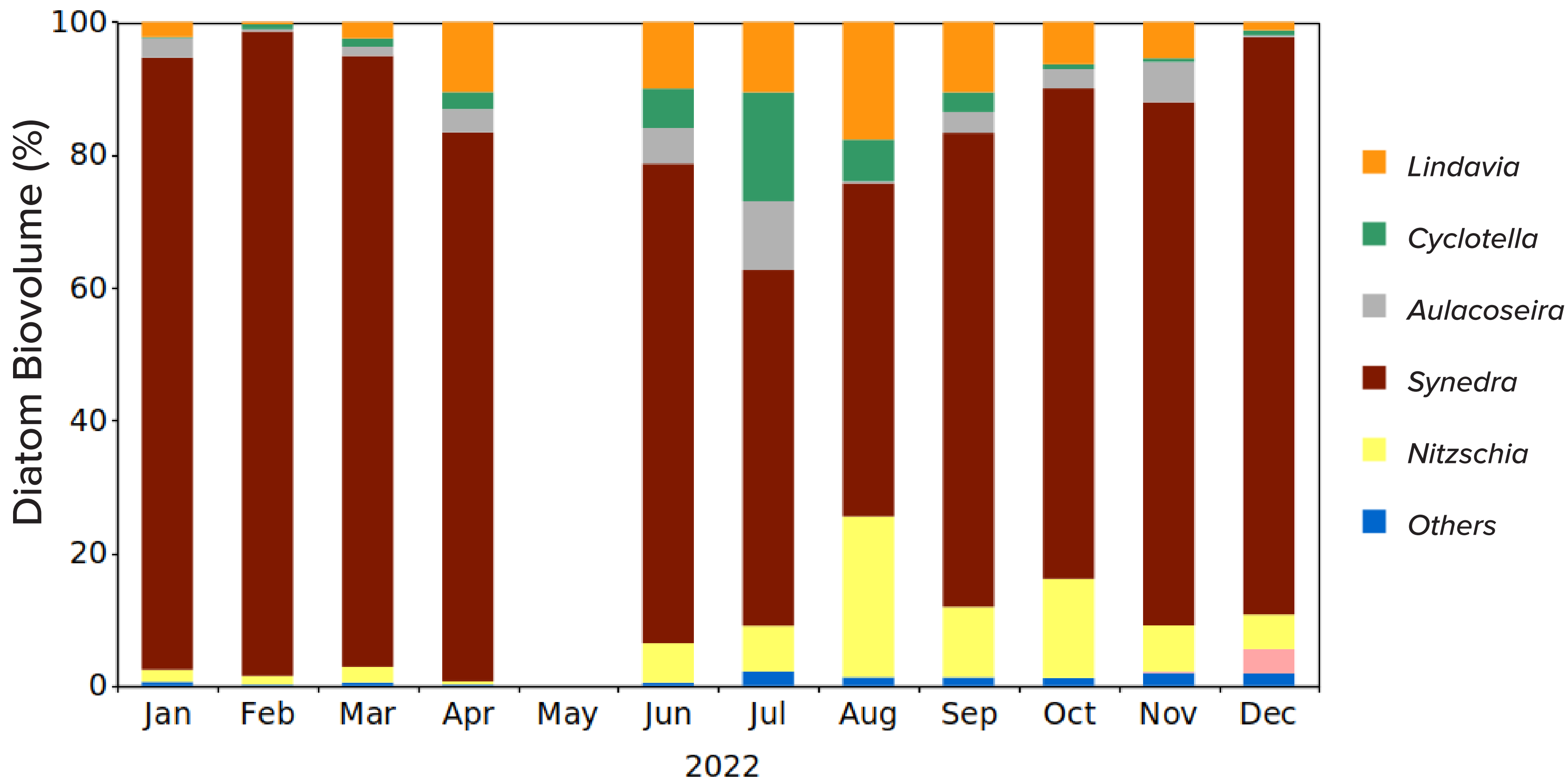


Abundance of dominant diatom species

Monthly in 2022

Since regularly monitoring commenced in 1982, diatoms have been the dominant algal group at Lake Tahoe for all but a few years. Diatoms are unique in that they contain a cell wall made of silica, called a frustule. The dominant diatoms at Lake Tahoe in 2022 are shown below. Normally there are large variations in the relative composition by month. In 2022, *Synedra* was dominant in terms of biovolume, forming the majority of the diatom biovolume during every month.

Data source: TERC lake monitoring.



Mysis population

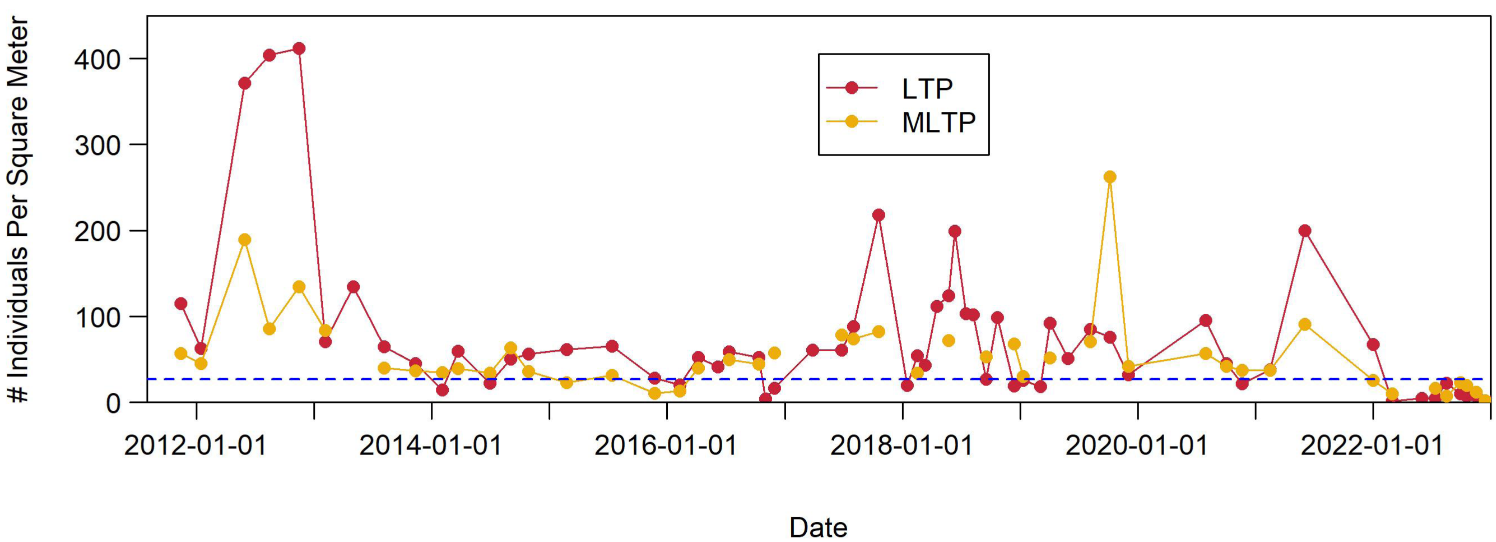
Since 2012

Mysis shrimp were introduced to Lake Tahoe in the 1960s in an attempt to improve the size of game fish in the lake. The intended result did not occur and instead the *Mysis* upset the existing lake food web. Within four years of their introduction, they had decimated the populations of the native cladocerans (*Daphnia* and *Bosmina*). Since that time, these zooplankton are rarely observed. *Daphnia* and *Bosmina* were once an important food source for native minnows, which in turn provided food for kokanee salmon and rainbow trout.

In the 1980s, research on *Mysis* essentially stopped. However, since 2012, TERC has recommenced regular surveys of Lake Tahoe and Emerald Bay. *Mysis* migrate to the lake bottom during the day, requiring all sampling to occur at night. The sampling net is pulled vertically in Lake Tahoe at 3-month intervals from three sites: South Shore Deep (200 m), LTP Index (100 m), and MLTP (200 m). Since early 2022, sampling has increased to monthly intervals.

The *Mysis* densities (number of individuals collected divided by the net opening area) in Lake Tahoe show considerable variability. The blue dashed line at 27 individuals per square meter represents the *Mysis* population level below which cladocerans can reestablish. In early 2022, *Mysis* numbers fell below that threshold and remained low through the end of the year. As *Mysis* in Lake Tahoe generally exhibit three- to four-year classes, the absence of all age classes suggest that it may take several years for the *Mysis* population to rebuild. It is hypothesized that *Daphnia* and *Bosmina* populations will increase in 2023, potentially bringing a significant increase in lake clarity.

Data source: TERC lake monitoring.



Zooplankton populations

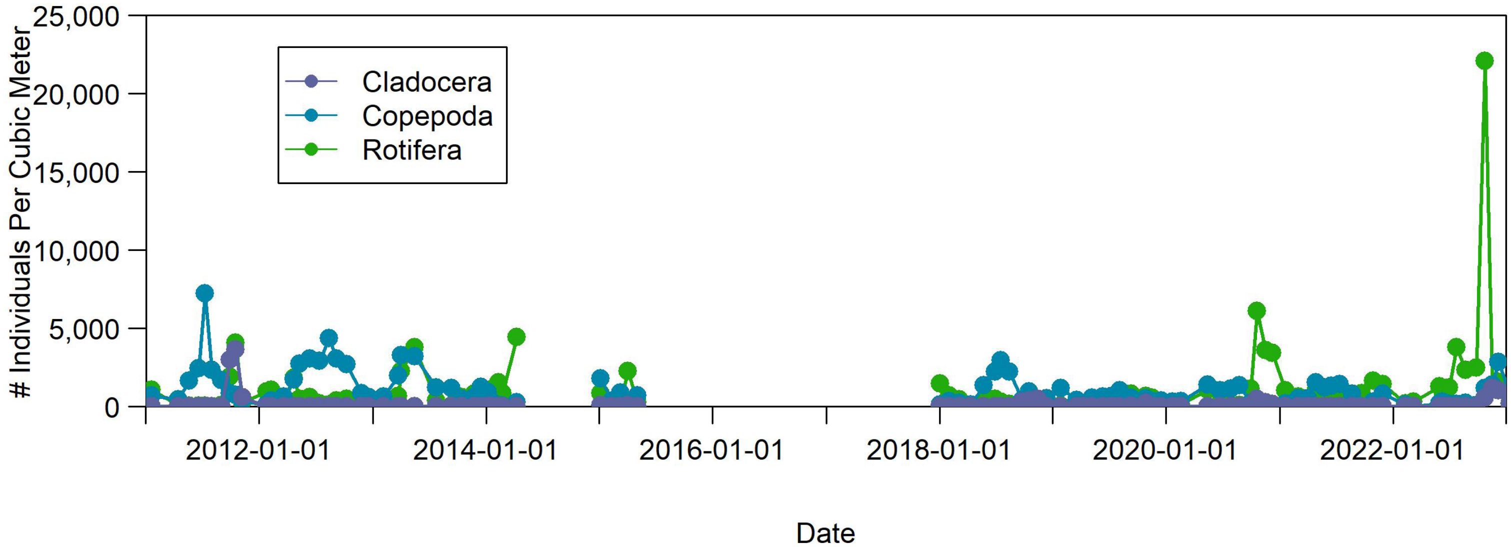
Since 2012

The zooplankton populations in Lake Tahoe have been monitored episodically since the 1960s, but due to a lack of funding there are many data gaps. Since 2012, TERC has sought to re-establish monitoring. The data shown below are from the LTP site, where zooplankton were collected with replicate vertical trawls from a depth of 330 feet to the surface during the middle of the day.

The figure shows the abundance of three groups of zooplankton — cladocerans (*Daphnia* and *Bosmina)*, copepods (*Epischura* and *Diaptomus*), and rotifers. The cladocerans are typically at very low values, a feature that first occurred after the introduction of *Mysis* shrimp in the 1960s. Notably at the end of the record, in September 2022, their numbers increase. The copepods are generally variable, but in late 2021 their numbers collapsed possibly due to a fungal infection.

The rotifers are also variable over time, but in mid-2022 their abundances increased dramatically.

Data source: TERC lake monitoring.

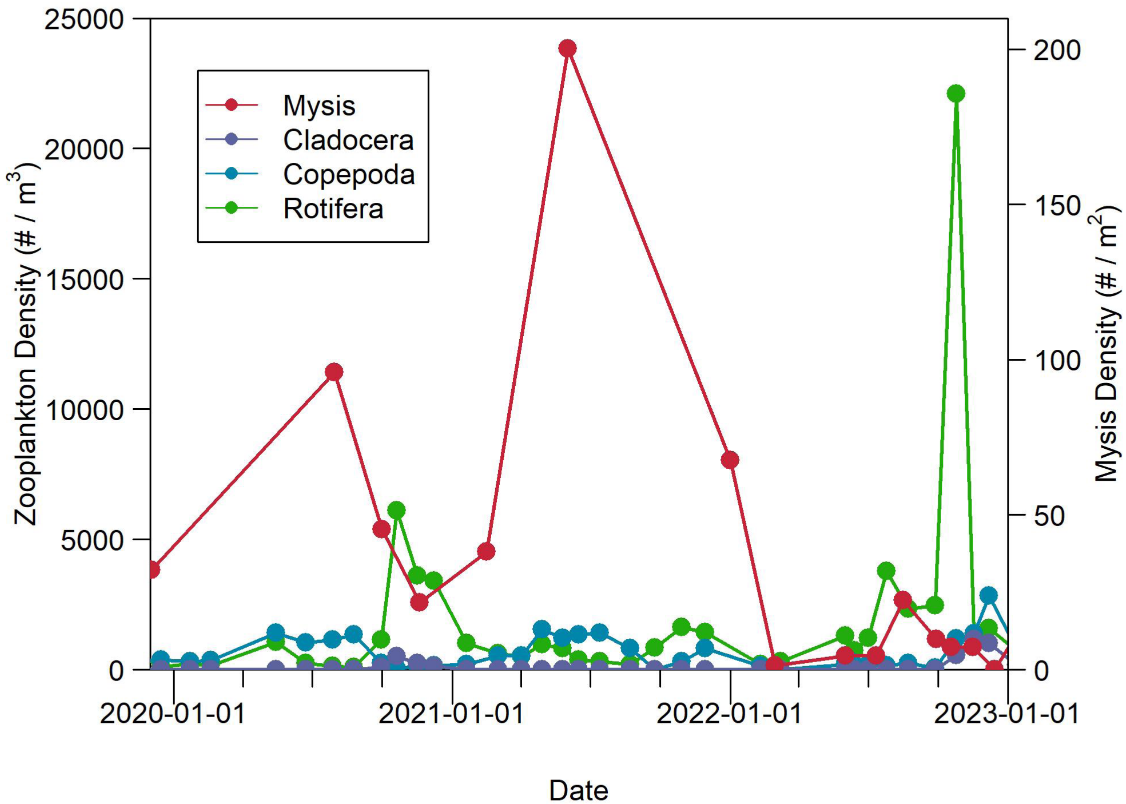


Zooplankton and *Mysis* populations

Since 2020

Below are the combined data from Figures 10.9 and 10.10 for the period January 2020 through December 2022. The changes in zooplankton and *Mysis* populations referred to in the previous two pages are more clearly seen here. Most notably those changes include the collapse of the copepod population, followed by the collapse of the *Mysis* population, followed by the increase in the rotifer population, and finally the increase in the cladocerans population.

It is noteworthy that during this period of time when there are major shifts in the Mysis and zooplankton populations, there were, at the same time, major changes in the primary productivity and the algal biovolume described previously. Additionally, the number of fine particles in the upper 50 meters of the lake (Fig. 9.9), the major determinant of lake clarity, also fell to their lowest concentration since 2016.



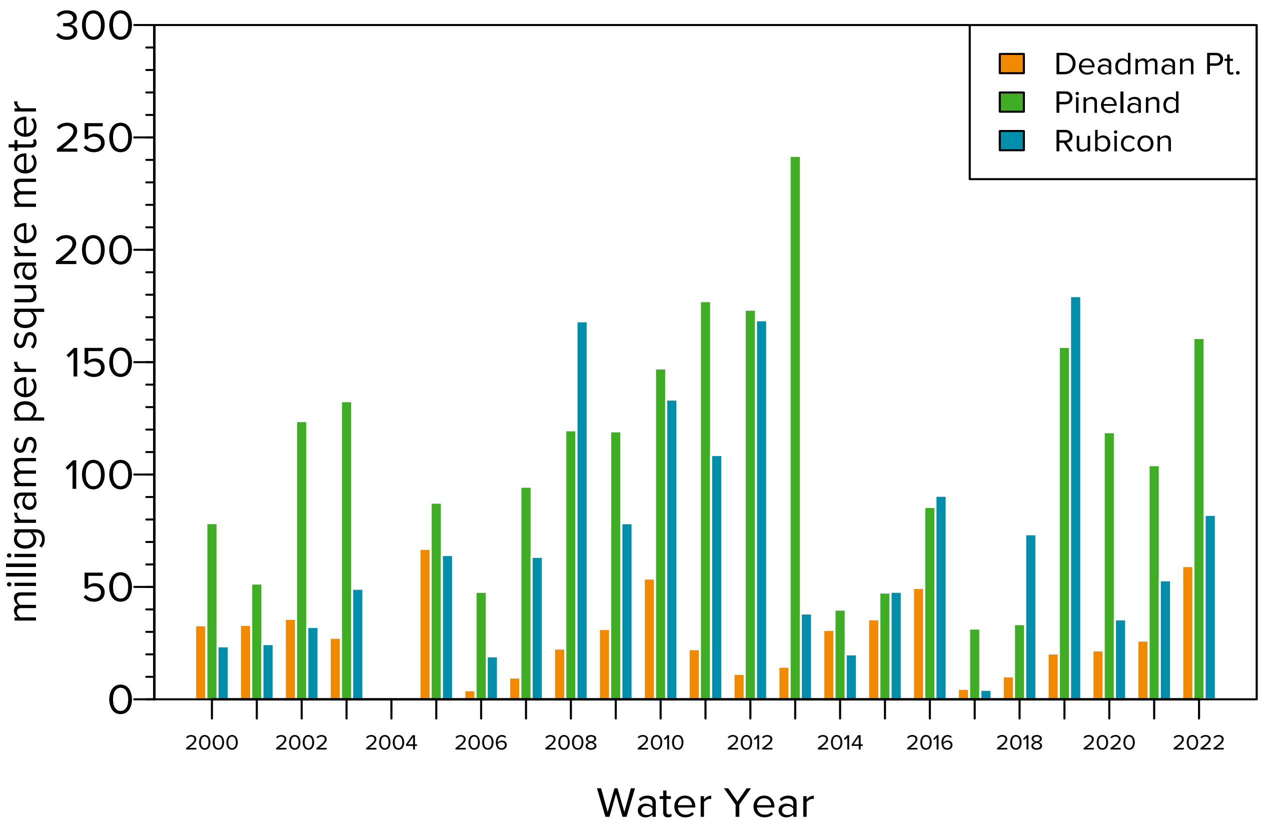
Peak shoreline algae concentrations

Yearly since 2000

Periphyton, or attached algae, makes rocks around the shoreline of Lake Tahoe green and slimy, or they sometimes form a very plush white carpet after being sun-bleached. This graph shows the maximum biomass measured at 1.5 feet (0.5 m) below the surface at three sites from January to June. In 2022, concentrations at the Deadman Point, Pineland, and Rubicon sites were all above their long-term average.

In 2023, TERC will be adopting a whole-lake aerial approach to better represent the spatial extent of periphyton blooms. During the latter part of 2022, there were widespread algal blooms in the northwest and southern shores of Lake Tahoe. The current sampling protocol of measuring at specific sites does not capture the critically important spatial extent of periphyton blooms.

Data source: TERC lake monitoring.



Shoreline algae distribution

In 2022

Periphyton biomass was surveyed around the lake over a three-week period during the spring of 2022, when periphyton is usually at its annual maximum. Over 50 locations were inspected by snorkel survey in 1.5 feet (0.5 m) of water. A Periphyton Biomass Index (PBI) is used as an indicator to assess levels of periphyton. The PBI is defined as the fraction of the local bottom area covered by periphyton multiplied by the average length (cm) of the algal filaments. There were more sites with a high PBI in 2022 than the previous year. The majority of the high PBI sites were on the California side. Most of the east shore had relatively low growth. This is in part a reflection of the high wave activity that causes the periphyton to slough, as well as generally lower amounts of precipitation and runoff along the east shore.

2022 was unusual in that periphyton peaked many months later than the usual spring bloom. Because of this the figure does not fully represent the severity of the 2022 algal bloom.

Data source: TERC lake monitoring.

Note: The width of the colored band does not represent the actual dimension of the onshore-offshore distribution. Similarly, its length does not represent the precise longitudinal extent.

Distribution of Periphyton Biomass at 0.5m Depth, Spring 2022